

# PATENT SPECIFICATION

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## (54) WELL LOGGING METHOD AND APPARATUS

(71) We, TEXACO DEVELOPMENT CORPORATION, a corporation organised and existing under the laws of the State of Delaware, United States of America, of 5 135 East 42nd Street, New York, New York 10017, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, 10 to be particularly described in and by the following statement:—

This invention relates to radiological well logging methods and apparatus for investigating the lithological characteristics of sub-surface earth formations traversed by a bore-hole and, more particularly, relates to improved neutron-gamma ray logging methods and apparatus.

It is well known that oil and gas are 20 more likely to be found in commercially recoverable quantities in those earth formations which are relatively porous and permeable than in the more highly consolidated formations. It is also well known that an oil or 25 gas-filled strata may be located by passing a neutron source through the borehole and measuring the intensity of secondary gamma radiations which are produced at various depths in the borehole. A chlorine nucleus 30 has a thermal neutron capture cross section which is much higher than that of nuclei of most of the other elements which are found in greatest abundance in the earth, and thus a salt water filled limestone or sandstone 35 layer will have a greater macroscopic thermal neutron capture cross section than will an oil saturated layer. Accordingly, this difference can be observed by measuring either chlorine capture gamma rays or the life-time of the 40 thermal neutron population in the layer.

Although these logging techniques have long been used, and although a great many oil or gas-bearing formations have been found in this manner, they have also produced a great many spurious indications. This is because many porous earth formations

contain low salinity water, which is indistinguishable from oil using these methods.

Thus, the intensity of the capture gamma radiation which is detected at various bore-hole depths is an indication of fluid salinity and porosity, and is not necessarily conclusive evidence that an oil-bearing formation has been discovered. An inelastic gamma ray spectrum, however, is independent of salinity since chlorine has a small inelastic cross section.

The carbon nuclei in the oil will, to a limited extent, also engage in capture interactions with bombarding neutrons, although the thermal neutron capture cross section of carbon is extremely low, and this is also true for oxygen nuclei. However, the inelastic scattering reaction cross section is appreciable for both carbon and oxygen if the collision energy of the neutron is sufficiently high. Furthermore, the initial energies of the gamma rays resulting from carbon are distinctively different from that of gamma rays resulting from oxygen when this reaction occurs. Accordingly, it has long been assumed that a measurement of inelastic scattering gammas could provide the basis for a technique for detecting and identifying an oil or gas-bearing earth formation as opposed to a water-bearing formation as such.

Many attempts have been made to employ this concept in well logging. Thus far, however, none of the methods and apparatus which utilize this concept have been reliable.

One of the principal reasons for this lack of success is that carbon is one of the most common elements in the earth's crust. Moreover, a limestone formation is largely composed of calcium carbonate, and thus a water-bearing limestone formation will frequently emit more carbon gammas than will an oil-filled sand or shale.

Another problem is that a gamma ray tends to readily engage in scattering reactions itself and further tends to lose energy to

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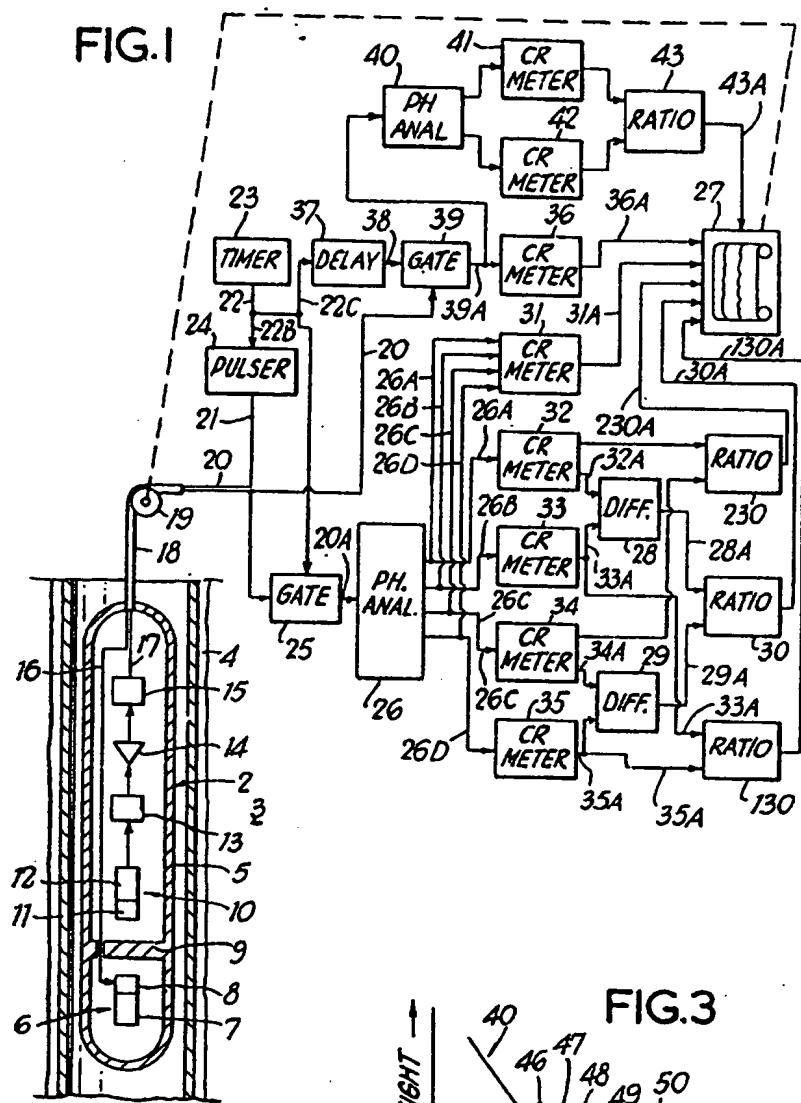
## **COMPLETE SPECIFICATION**

2 SHEETS

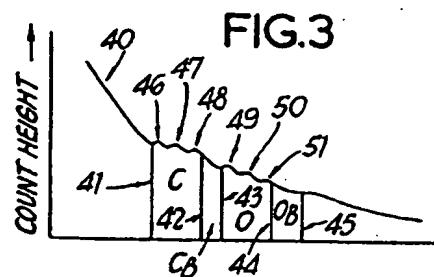
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Sheet 1

**FIG. I**



**FIG.3**



exhibits a thermal capture gamma ray peak at approximately 3.54 Mev. It is also known that calcium exhibits a thermal neutron capture gamma peak at approximately 6.41 Mev.

5 Discrete energy windows to measure the relative magnitude of these two known peaks, in pulse height analyzer 40, however, are preferably not chosen symmetrically about these energies. Interference from capture gammas from other formation and borehole elements has led to the choice of an energy window in the 2.5 to 3.2 Mev. range to detect the Si peak and an energy window in the 5.2 to 6.25 Mev. range to detect the Ca peak.

10 The output of the counts in each of these respective energy windows from pulse height analyzer 40 are supplied to a ratio meter 43 which produces an output signal 43A proportional to the Si/Ca ratio based on this two energy window measurement. The lithology signal 43A may then be recorded on a recorder 27 in depth correlation with the previously discussed signals 30A, 130A, 31A and 36A.

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**WHAT WE CLAIM IS:—**

1. A method of investigating a subsurface earth formation traversed by a borehole, comprising
- 20 generating a population of high energy neutrons in said borehole and formation, detecting gamma rays resulting from interactions between said neutrons and bombarded nuclei in said formation,
- 25 deriving electrical pulses having amplitudes functionally corresponding to said detected gamma rays,
- 30 making a time-dependent selection of those of said pulses corresponding to those detected gamma rays resulting from inelastic scattering of said neutrons by said bombarded nuclei,
- 35 deriving from said time-dependent selection a first energy-dependent selection of those pulses corresponding to gamma rays attributable to inelastic scattering of said neutrons by carbon nuclei,
- 40 deriving from said time-dependent selection a second energy-dependent selection of those pulses corresponding to gamma rays attributable to inelastic scattering of said neutrons by oxygen nuclei,
- 45 deriving the ratio of a function of said first energy-dependent selection to said second energy-dependent selection,
- 50 deriving from said time-dependent selection a third energy-dependent selection of those pulses attributable to carbon background radiation,
- 55 deriving from said time-dependent selection a fourth energy-dependent selection of those pulses attributable to oxygen background radiation, and
- 60 deriving said ratio as a function of said

first, second, third and fourth energy-dependent selections.

2. A method as claimed in claim 1, wherein said step of deriving said ratio includes the steps of:

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70 deriving as an indication of the magnitude of the carbon nuclei in said formation the difference between said first energy-dependent selection and a function of said third energy-dependent selection;

75 deriving as an indication of the magnitude of the oxygen nuclei in said formation the difference between said second energy-dependent selection and a function of said fourth energy-dependent selection; and

80 deriving as an indication of the ratio of carbon and oxygen in said formation the ratio of said difference between first and third energy-dependent selections to the difference between said second and fourth energy-dependent selections.

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3. A method as claimed in claim 1 or claim 2, further including the steps of:

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95 deriving a function of the summation of said first, second, third and fourth energy-dependent selections; and

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100 recording said function of said summation to indicate porosity in conjunction with said indication of said ratio of carbon and oxygen together with a correlative indication of borehole depth.

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4. A method as claimed in claim 3, further including the steps of:

making a second time-dependent selection of those of said pulses corresponding to those selected gamma rays resulting from capture of said neutrons by bombarded nuclei;

recording said second time-dependent selection in correlation with the record of said ratio and summation to obtain a measurement of the porosity of said formation.

5. A method as claimed in claim 4, further including the steps of:

making, during said second time-dependent selection, a further energy-dependent selection of those pulses corresponding to gamma rays attributable to capture of said neutrons by at least two selected elements in the earth formation in the region of the borehole; and

recording signals representative of said further energy-dependent selection made during said second time-dependent selection as an indication of formation lithology.

6. A method as claimed in claim 4, wherein the elements selected during said second time-dependent selection and said further energy-dependent selection are silicon and calcium, which are selected by using energy windows in the 2.5 to 3.2 Mev. range for silicon and 5.2 to 6.25 Mev. range for calcium respectively.

7. A method as claimed in any one of claims 1 to 6, wherein the earth formation